PROSPECTS FOR HIGGS SEARCHES VIA VBF AT THE LHC WITH ATLAS [a]

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We report on the potential for the discovery of a Standard Model Higgs boson with the vector boson fusion mechanism in the mass range $115 < M_H < 500\,\mathrm{GeV/c^2}$ with the ATLAS experiment at the LHC. Feasibility studies at hadron level followed by a fast detector simulation have been performed for $H \rightarrow W^{(*)}W^{(*)} \rightarrow l^+l^-\not{p}_T$, $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow l^+l^-q\overline{q}$. The preliminary results obtained here show a large discovery potential in the range $115 < M_H < 300\,\mathrm{GeV/c^2}$. Results obtained with multivariate techniques are reported for a number of channels.

1 Introduction

In the Standard Model (SM) of electro-weak and strong interactions, there are four types of gauge vector bosons (gluon, photon, W and Z) and twelve types of fermions (six quarks and six leptons). These particles have been observed experimentally. The SM also predicts the existence of one scalar boson, the Higgs boson. The observation of the Higgs boson remains one of the major cornerstones of the SM. This is a primary focus of the ATLAS Collaboration [1].

The Higgs at the LHC is produced predominantly via gluon-gluon fusion [2]. For Higgs masses, M_H, such that $M_H > 100\,\mathrm{GeV/c^2}$, the second dominant process is vector boson fusion (VBF) [3,4].

Early analyses performed at the parton level indicated a strong discovery potential with the decays $H \rightarrow W^{(*)}W^{(*)}$, $\tau^+\tau^-, \gamma\gamma$ associated with to hard jets in the range $115 < M_H < 200\,\mathrm{GeV/c^2}$ [5,6,7,8]. The ATLAS collaboration has performed feasibility studies for these decay modes including more detailed detector description and the implementation of initial-state and final-state parton showers, hadronization and multiple interactions [9].

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Table 1: Expected signal and background effective cross-sections (fb) and the corresponding Poisson significance for the $H \rightarrow W^{(*)}W^{(*)} \rightarrow l^+l^-\not{p}_T$ decay mode associated with two hard jets with $10\,\mathrm{fb}^{-1}$ of integrated luminosity. A 10% systematic uncertainty is applied to all backgrounds when calculating the significance.

M_H(GeV/c^2)	S	B	Significance (σ)
115	0.64	1.84	1.4
130	2.36	2.34	4.3
160	9.29	3.62	11.6
200	6.28	8.09	6.0
300	4.34	14.4	3.1
500	1.18	5.10	1.5

Here, we present an update of the potential of observing the SM Higgs boson via VBF with $H \rightarrow W^{(*)}W^{(*)} \rightarrow l^+l^-\not{p}_T$, where $\not{p}_T$ stands for missing transverse momentum carried by neutrinos. This analysis has been extended to larger Higgs masses. Also, we investigated the prospects of observing a SM Higgs boson with $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow l^+l^-q\bar{q}$. Results obtained with multivariate techniques are reported for a number of channels. Finally, the status of the overall SM Higgs discovery potential of the ATLAS detector is presented.

2 Experimental Signatures

The VBF mechanism displays a number of distinct features, which can be exploited experimentally to suppress SM backgrounds: Higgs decay products are accompanied by two energetic forward jets originating from incoming quarks and suppressed jet production in the central region is expected due to the lack of color flow between the initial state quarks. In this paper, tagging jets are defined as the highest and next highest transverse momentum, P_T, jets in the event. The tagging jets are required to be well separated in pseudorapidity and to be in opposite hemispheres and to have a large invariant mass.

The following decay chains have been considered in the analysis: $H \rightarrow W^{(*)}W^{(*)} \rightarrow l^+l^-\not{p}_T$, $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow l^+l^-q\bar{q}$. A number of relevant experimental aspects have been addressed in detail in [1,9] and will not be touched upon here: triggering, lepton and photon identification, fake lepton and photon rejection, jet tagging, central jet veto and b-jet veto efficiencies. Details on specific event selections chosen for each particular Higgs decay reported here are available in [10].

3 The $H \rightarrow W^{(*)}W^{(*)} \rightarrow l^+l^-\not{p}_T$ Mode Associated with Two Hard Jets

A study of this mode at hadron level followed by a fast simulation of the ATLAS detector was first performed in [11]. We report on a re-analysis over a broader mass range $115 < M_H < 500\,\mathrm{GeV/c}^2$. Additionally, the treatment of the main background process is improved in the present analysis and a mass dependent event selection has been developed and implemented [10]. The proper modelling of $t\bar{t}$ production associated with jets is crucial to understanding the feasibility of this final state. For this purpose, we used the MC package MC@NLO, which merges consistently Next-to-Leading Order matrix elements with a parton shower [15].

The central jet veto survival probability for $t\bar{t}$ production is significantly lower than that reported in [9]. However, this is compensated by a lower rejection due to requiring two tagging jets. As a result, the relative contribution to the background from $t\bar{t}$ production obtained here is similar to the one reported in [9]. Table 1 reports the expected signal and background effective cross-sections (in fb) with the corresponding Poisson significance for $10\,\mathrm{fb}^{-1}$ of integrated

luminosity. Simple event counting is used and a 10 % systematic error on the background determination was assumed. In order to implement the systematic errors we incorporated [12,13] the formalism developed in [14]. The $H \rightarrow W^{(*)}W^{(*)} \rightarrow l^+l^-\not{p}_T$ mode has a strong potential in a wide rage of Higgs masses. A significance of or greater than $5\,\sigma$ can be achieved with $30\,\mathrm{fb}^{-1}$ of integrated luminosity for $125 < M_H < 300\,\mathrm{GeV/c}^2$ [10].

4 The $H \rightarrow \gamma\gamma$ Mode Associated with Two Hard Jets

This analysis was performed at parton level first in [8]. The relevant background processes for this mode are subdivided into two major groups. Firstly, the production of two γ's associated with two jets (real photon production). Secondly, a sizeable contribution is expected from events in which at least one jet is misidentified as a photon (fake photon production). Despite the impressive jet rejection expected to be achieved by the ATLAS detector [1] ($\gtrsim 10^3$ for each jet), the contribution from fake photons will not be negligible due to the large cross-sections of QCD processes at the LHC.

The contribution from the fake photon background has been severely reduced due to the inclusion of the photon angular variables. The contribution from this background, however, is important. The normalization of the fake photon background is subject to sizeable systematic uncertainties. This is partly due to the uncertainty on the determination of the fake photon rejection rate [1]. The signal significance expected with this VBF mode alone reaches $2.2\,\sigma$ for 30 fb^{-1} of integrated luminosity [16,10]. The background estimation can be improved with the implementation of a more realistic MC for the simulation of the real photon background. This mode is considerably more sensitive to the understanding of fake photon rejection than the inclusive analysis [1]. A signal-to-background ratio of 0.5 or better can be achieved, which gives room to less stringent requirements on systematic errors. In real data the background normalization can be obtained using side bands.

5 The $H \rightarrow ZZ \rightarrow l^+l^-q\overline{q}$ Mode Associated with Two Hard Jets

The main background corresponds to the production the QCD $Z + 4j, Z \rightarrow l^+l^-, l = e, \mu$. Diagrams with one or two EW boson in the internal lines were neglected. The contribution from $t\bar{t}$ is small and it is also neglected.

A feature specific to the mode under study is the additional ambiguity in the definition of tagging jets introduced by the presence of relatively hard jets produced from the decay of the Z's. A search for two jets with an invariant mass close to the Z mass, M_Z, is performed. After reconstructing the Z decaying hadronicaly, the event looks like a "typical" VBF candidate.

Due to the application of kinematic fits, an average relative invariant mass resolution of 2.5% can be obtained. A signal significance of $3.75\,\sigma$ can be achieved for $200 < M_H < 300\,\mathrm{GeV/c}^2$ with $30\,\mathrm{fb}^{-1}$ of integrated luminosity [10]. It should be noted that the cross-sections for the main background reported here are subject to large theoretical uncertainty. Fortunately, the background can be determined from side bands for Higgs searches with $M_H > 200\,\mathrm{GeV/c}^2$. The main source of systematic errors are due to the energy scale uncertainty of hadronic jets. The energy scale of hadronic jets should be known to 2% in order to achieve a 10% error on the background normalization.

6 Multivariate Analysis

Results reported in [9] and the present paper were based on classical cut analyses. Multivariate techniques were used extensively in physics analyses, for instance, in LEP experiments. Neural Networks (NN) are the most commonly used tools in multivariate analyses. NN training has

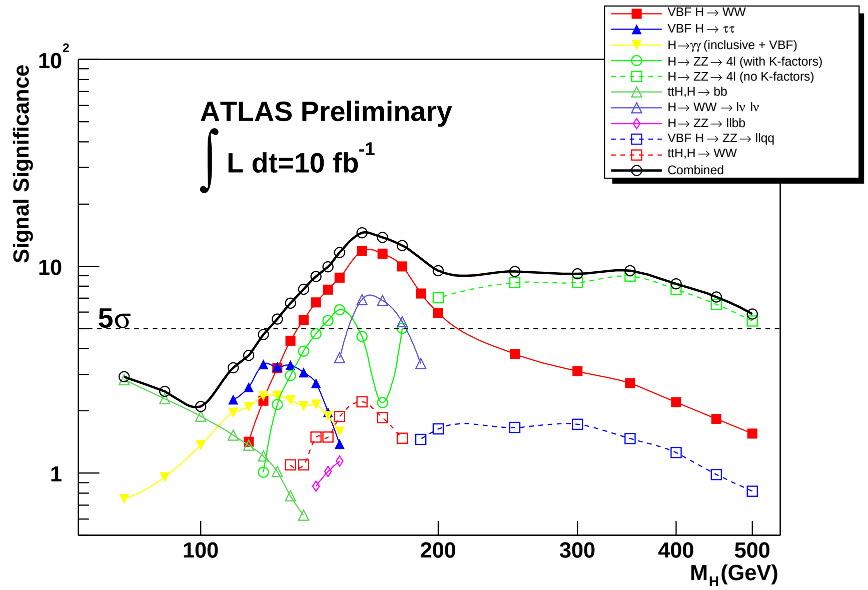

Figure 1: Expected significance for ATLAS (preliminary) as a function of Higgs mass for $10\,\mathrm{fb}^{-1}$ of integrated luminosity.

been performed on the $H \to W^{(*)}W^{(*)} \to l^+l^-\not{p}_T$ [17] and $H \to \tau^+\tau^- \to l^+l^-\not{p}_T$ [18] modes. NN training was performed with a relatively small number of variables. It was required that these variables are infra-red safe and their correlations do not depend strongly on detector effects. The signal significance was calculated with a likelihood ratio technique using the NN output as a discriminant variable[12,13]. An enhancement of approximately $30-50\,\%$ of the signal significance with respect to the classical cut analysis was obtained for both modes under consideration.

7 Conclusions

The discovery potential for the SM Higgs boson associated with two hard jets in the range $115 < M_H < 500\,\mathrm{GeV/c^2}$ has been reported. An updated study at hadron level followed by a fast detector simulation of the $H \to W^{(*)}W^{(*)} \to l^+l^-\not{p}_T$ mode has been presented: the main background, $t\bar{t}$ associated with jets, has been modelled with the MC@NLO program and the Higgs mass range has been extended to $500\,\mathrm{GeV/c^2}$. This mode has a strong potential: a signal significance of more than $5\,\sigma$ can be achieved with $30\,\mathrm{fb}^{-1}$ of integrated luminosity for $125 < M_H < 300\,\mathrm{GeV/c^2}$. The discovery potential of the $H \to \gamma\gamma$ and $H \to ZZ \to l^+l^-q\bar{q}$ modes have also been reported. The discovery potential of the $H \to \tau\tau$ modes have not been updated here.

The discovery potential of the modes presented here was combined with results reported in past studies performed for the ATLAS detector. For the purpose of the combination the results reported in [9] were used. Results from recent studies [19,20,21], which were not used in [9], were added here. Likelihood ratio techniques have been used to perform the combination [12,13]. In order to incorporate systematic errors, the formalism developed in [14] was implemented. A $10\,\%$ systematic error on the background estimation has been assumed for modes related to VBF [9]. This issue needs to be addressed in more detail using control samples with full simulation. Figure 1 displays the overall discovery potential of the ATLAS detector with $10\,\mathrm{fb}^{-1}$ of integrated luminosity. Results from NN based analyses and discriminating variables have not been included in the combination. The present study confirms the results reported in [5,6,7,8,9], that the VBF mechanism yields a strong discovery potential at the LHC in a wide range of the Higgs boson mass.

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